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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Interim Report for AES Flight Mission Assignment Plan: Part IV - LEM Derivatives (U)

Ref. No. 65-2021
TM- 65-1011-3

FILING CASE NO(S)- 218

DATE- January 29, 1965

AUTHOR(S)- J. E. Waldo

FILING SUBJECT(S)- (ASSIGNED BY AUTHOR(S)) Apollo Extension Systems

CLASSIFICATION CHANGED
UNCLASSIFIED
TO
By Authority of The Bellcomm Date 12-1-70

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(NASA-CR-111435) AES FLIGHT MISSION ASSIGNMENT PLAN. PART 4 - LEM DERIVATIVES (Bellcomm, Inc.) 25 p

N79-72025

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ABSTRACT

A fundamental approach in the Apollo Extension Systems (AES) is maximum utilization of Apollo spacecraft and spacecraft systems. This report considers four derivatives of the Lunar Excursion Module (LEM) chosen on the basis of (1) type of AES missions and objectives, (2) AES ground rules limiting modification of spacecraft and facilities, and (3) preferred or suggested primary modes of LEM and CSM usage.

These derivatives are the LEM-Lab, a laboratory for orbital missions completely dependent on the CSM; the Earth-Orbit LEM, an independent, separable laboratory; and the LEM-Shelter and LEM-Taxi, two derivatives for delivering the crew and payload for extended lunar surface missions. All of these modified spacecraft appear to be both suitable and obtainable for the AES missions; however, the requirements to be met vary considerably and would result, in some cases, in extensive modification of the Apollo LEM systems.

The LEM-Lab could provide approximately 240 cu. ft of pressurized volume and weigh 1250 lbs. The unresolved areas are largely in how the LEM-Lab can be used rather than specific problem in the modification.

The Earth-Orbit LEM would retain most of the present LEM functions because of independent operation. The potential of supplementing the CSM for extended missions merits study.

BA-145B (8-64)

FF No. 602(A)

X70-77369 (ACCESSION NUMBER)	(THRU)
25 (PAGES)	(CODE)
CR-111435 (NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

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The LEM-Shelter/LEM-Taxi combination could provide lunar surface staytimes of approximately 14 days with payloads of approximately 3000 lbs. Questionable and problem areas arise primarily because of thermal control and electrical power requirements during pre-utilization storage of the Shelter and storage of the Taxi during the mission. Other problems associated with extended mission time are radiation hazard to the crew and abort capability.

Weights are estimated in a classified appendix (CONFIDENTIAL); and major problem areas, significant changes, and unresolved or questionable areas for the four derivatives are noted.

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SUBJECT: Interim Report for AES Flight Mission Assignment Plan: Part IV - LEM Derivatives (U) Case 218

DATE: January 29, 1965

FROM: J. E. Waldo

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1.0 INTRODUCTION

The Apollo LEM is directed toward the single objective of a manned lunar landing, but inherently possesses the potential to perform many functions in an AES-type program. The purpose of the LEM derivatives is to extend the capability of the nominal Apollo LEM to support AES orbital and surface missions. LEM derivatives to be considered for the current study are bounded in scope by (1) the type of AES missions and objectives, (2) AES ground rules limiting modification of spacecraft and facilities, and (3) preferred or suggested primary modes of LEM and CSM usage.

For orbital missions, LEM derivatives may be expected to provide one or more of the following capabilities:

(1) additional pressurized volume as a laboratory for the crew and experiments

(2) internal and external storage of experimental payloads

(3) additional reaction control and propulsion capability

(4) maneuvering capability separated from the CSM.

For extended lunar surface missions, LEM derivatives may be expected to provide:

(1) delivery of crew from lunar orbit and return to rendezvous with CSM

(2) delivery and support of scientific payloads, including mobility aids

(3) crew shelter, life support, and working space on the surface.

Within this framework the LEM derivatives for the suggested AES missions can be grouped into four basic types:

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LEM-Lab - A modified LEM ascent stage attached to the CSM for use as a laboratory in earth and lunar orbital missions. The descent stage may be used if additional propulsion is required.

Earth-Orbit LEM - A modified LEM for use with the CSM as an independent, separable spacecraft in extended earth orbital missions.

LEM-Shelter - A modified LEM delivered unmanned from lunar orbit to the lunar surface to provide shelter for an extended surface mission of the LEM taxi crew.

LEM-Taxi - A modified LEM for delivery of two men near the LEM shelter on the lunar surface, quiescent storage during the extended surface mission, and return of the crew to the CSM in lunar orbit.

This report is concerned with a discussion of each of these derivatives, the modifications to the Apollo LEM which appear to be required, and some possible problem areas. Weight calculations are contained in the Appendix, which is classified CONFIDENTIAL.

2.0 LEM DERIVATIVES

The suggested functions of the LEM derivatives and the required modifications are sufficiently different that four basic types result. In this section these derivatives and some possible problem areas are briefly discussed. The problem areas are recognized as being typical of many certain to arise and, although representative, are not necessarily <u>the</u> high risk areas or critical items.

2.1 LEM-Lab

The primary function of the LEM-Lab would be to provide additional pressurized volume for the crew and experiments in orbital missions. There are several approaches which differ in the extent of modification to the Apollo LEM and the degree to which the module is to be dependent on the CSM. A secondary function would be to provide additional propulsion and maneuvering capability through the use of the LEM ascent or, more likely, descent propulsion.

The maximum modification LEM-Lab, in the sense of the ground rules, would be essentially a stripped ascent stage structure to which has been added meteoroid shielding for extended mission periods and the minimum hardware required to use CSM environmental control and electrical power. The LEM-Lab is assumed to be completely dependent on the CSM for life support, environmental control and electrical power. Typical added hardware would be wiring for lighting and experiments, fan and ducting for ventilation, a CSM intercom with provision for communicating with extra-vehicular crew, and similar items. Such a LEM-Lab would provide approximately 240 cu. ft. of pressurized volume and weigh approximately 1250 lbs. Respective figures for an unmodified LEM ascent stage are 180 cu. ft. and 4000 lbs. For all such cases without the descent stage an estimated 400 lbs. of additional structure would be required for ascent stage mounting in the adapter.

The current Apollo LEM could serve as a lab in unmodified form by simply offloading propellants and expendables. There is a weight penalty, and storage space is somewhat more limited than in a completely stripped ascent stage. However, the unmodified LEM has the advantages of availability for early missions, the presence of subsystems to back up or supplement CSM subsystems, and the ability to maneuver as a separate module. The latter is of interest in earth-orbital missions and has been defined as a function of the Earth-Orbit LEM, another separate LEM derivative.

The unresolved or questionable areas are largely in how the LEM-Lab can be used rather than in specific problems in the modification. The integration of experiments, storage of film and tape data, and crew activity are uncertain areas. For example, if there is to be extensive extravehicular activity, it may be advantageous to provide an airlock.

From the spacecraft point of view, integration of experimental equipment presents the problems of reducing effective internal volume useful to the crew and possible interference externally with spacecraft functions essential to the mission. In general, the locations and volumes available are known, but the selection, placement, and operation of experimental equipment will require extensive planning.

2.2 Earth-Orbit LEM

The function of the Earth-Orbit LEM would be to provide independent maneuvering capability when separated from the CSM. This derivative must retain most of the present LEM functions, as distinguished from the LEM-Lab, because it would be an independent module during at least part of the mission. The present subsystems may be suitable depending on the duration of the mission, the time separated, and the extent of dependence on CSM subsystems while docked. If closed-cycle ECS and EPS were used, the Earth-Orbit LEM could supplement the CSM for extended missions. The potential of this approach as opposed to increasing CSM capability should be studied.

2.3 LEM-Shelter

The primary purpose of the LEM-Shelter would be to provide crew shelter and the scientific payload for extended lunar surface missions. The Shelter will be delivered to lunar orbit by CSM, checked out, and then landed automatically, unmanned, at a preselected site. The LEM-Taxi, which delivers and returns the crew, may follow the LEM-Shelter by as much as 3 to 6 months. This interval establishes the pre-utilization storage period for the Shelter and represents the fundamental problem for this particular derivative of the LEM. Actual use of the Shelter and its payload would be for approximately two weeks. During this period the Taxi would be inactive and the crew would be entirely dependent on the Shelter.

The LEM-Shelter could be derived from the LEM by removing those subsystems not used, notably the ascent propulsion, and modifying or adding those required for the mission. The significant changes occur in cryogenic storage, obstacle avoidance for unmanned landing, meteoroid and radiation shielding, and electrical power.

Weights for the Shelter modification are difficult to determine because of sensitivity to mission operations and the existence of cutoff points beyond which an entire subsystem approach or configuration must be changed. Most problems arise in considering the storage phase -- where, when, how long, and extent of activity. Use of many of the present LEM subsystems is questionable unless the mission pair, the Shelter and Taxi, is restricted to a specific, tailored mission.

Present LEM systems would allow a surface storage period of up to about 12 days and an active period of 14 days, assuming the necessary expendables are carried in additional tanks of current LEM design and extra insulation is used. Storage of hydrogen appears to be the limiting factor. For the case above, the total hydrogen weight penalty would be approximately 1000 lbs. and represents a volume, rather than a weight, limitation. Storage periods beyond 12 days require new hydrogen tanks or more efficient hydrogen usage. The current open-cycle fuel cells require excess hydrogen, several times stoichiometric. If a closed-cycle EPS were used, the present tanks would provide 45 day storage for an 800 lb. penalty. It appears that development of new tanks and closed-cycle EPS and ECS will be required for storage periods of 3 to 6 months.

The duration, mode, and location of storage significantly influence the type of modifications for the shelter. It appears that the duration should be between 3 to 6 months to suit launch rates and desired flexibility, and that the storage mode should approach complete hibernation and independence of environment. The choice of storage location, whether in lunar orbit, on the surface, or a combination, is affected by several considerations.

Pertinent arguments favoring lunar orbit storage are that it presents less of an overall thermal problem because of reduction in the total heat load and variation in heat load, that the Taxi can land first and aid in Shelter descent, and that the mission is not immediately committed to a particular site. Although the overall thermal problem is reduced, the descent propellant temperatures would be a problem.

Arguments for lunar surface storage are that the Shelter position and status can be verified prior to Taxi launch, that the CSM can provide checkout prior to descent and can monitor the landing, and that the Shelter can provide a beacon for the Taxi. The importance of these factors must be determined before a decision can be made.

Radiation protection may also be a problem area. During a 14 day lunar surface mission, there is a probability of 0.75 of not exceeding the allowable radiation dose for the crew, based on the Apollo probability of 0.98 for a 1 day period. Thus, probability of abort from an unshielded LEM-Shelter because of radiation alone is 0.25 in 14 days.

Shielding to reduce this probability can be provided by additional LEM-Shelter mass, a storm shelter, or by covering the LEM-Shelter with lunar material. None of these approaches is particularly attractive.

Integral shielding requires structural modification and a significant part of the Shelter payload.

The storm shelter requires new development, complicates life support and ECS, and renders the crew ineffective for the period used.

Use of lunar material as a covering layer has the problems of unknown availability and characteristics, deposition, retention, and interference. The required thickness is estimated to be 1.5 inches or approximately 8 lb./sq. ft. for a probability of no abort of 0.98. Assuming this is not an excessive burden for the static Shelter and that retaining structure and a depositing device could be provided; there remains the question of whether crew time involved in the covering process provides an advantage on tradeoff with increase in total useful stay time, and the problem of interference with antennas, radiators, and thermal control surfaces.

In several cases the addition of an airlock would result in an lower overall weight, because of reduced spacecraft oxygen losses during crew egress-ingress cycles. The airlock considered for AES LEM derivatives is a structural, possibly inflatable, appendage attached to the outside of the forward hatch weighing approximately 100 lbs. Further overall weight reductions would be possible if the airlock were supplemented by pump down and storage of the airlock atmosphere. In both cases the cross-over point is relatively low, being in the neighborhood of 10 to 20 egress-ingress cycles, and can probably be justified on a weight basis for most of the extended-type missions considered for AES. Trace contamination buildup may be significant under such conditions and require intentional decompression as a system purge.

2.4 LEM-Taxi

The primary functions of the LEM-Taxi would be to deliver a two-man crew to the lunar surface for an extended Shelter mission and to return the crew to the CSM in lunar orbit. In effect, this means the LEM-Taxi and the associated CSM would perform the nominal Apollo mission with an extended waiting period of approximately 14 days between LEM descent and ascent.

Most modifications for a LEM-Taxi are expected to be in electrical power generation and thermal control and would be caused by the quiescent storage period and system status monitoring during this period. Specific modifications and the amount of additional expendables would depend on the environment and the extent to which storage is quiescent. Ideally, the LEM-Taxi would be completely inactive and thermal control would be by solely passive means. However, as presently conceived, some systems would be operating and electrical power and active thermal control would be required during the storage period.

The major problem in the proposed LEM-Taxi appears to be the weight penalty for modifications and expendables. Modifications are expected to be mainly insulation for propulsion and cryogenic tanks, additional tankage, increased meteoroid shielding, and fuel cells. Some current components may not be suitable for extended periods of operation. For example, ECS porous-plate water boiler performance may degrade with time because of buildup of contaminants. The use of present fuel cells is questionable because of their limited lifetime and the weight penalty for open-cycle operation during storage. Closed-cycle EPS and ECS, similar to the present CSM subsystems and those likely to be developed for the LEM-Shelter, would reduce this penalty. Other questionable areas concern inertial measuring unit temperature limits during the storage phase, abort capability, landing ejecta damage to the Shelter, communications on shared frequencies, and the mode and extent of status monitoring.

2.5 Alternate Uses of LEM Derivatives

Operational or scheduling constraints may favor or possibly dictate substitution of a LEM derivative in a mission for which it was not assigned. Alternate uses were considered for this reason and because of the potential reduction in the number of different spacecraft. Reduction to three basic types appears reasonable if the LEM-Lab and Earth-Orbit LEM could be combined, or if the LEM-Shelter could be used for Earth-Orbit LEM missions. Both approaches result in penalties. It was established, however, that the LEM-Shelter and the Apollo LEM could be useful alternatives for early orbital lab missions, although a weight penalty must be paid for this flexibility.

The primary objective is to provide additional pressurized volume for experiments and crew experimental work. LEM-Shelter volume should be approximately the same as the Apollo LEM ascent stage, estimated at 180 cu ft., as opposed to LEM-Lab volume of 240 cu. ft. The associated weights, assuming offloading of expendables only, are LEM ascent stage at 4000 lbs and LEM-Shelter ascent stage at 4500 lb. These weights represent penalties of 2800 lb. and 3300 lb. respectively, compared to the LEM-Lab weight of 1200 lbs.

SUMMARY

LEM derivatives, based on AES missions, ground rules and primary modes of LEM and CSM usage can be grouped into four basic types:

LEM-Lab - A modified ascent stage attached to the CSM for use as a laboratory in earth and lunar orbital missions. The primary function would be to provide additional pressurized volume for the crew and experiments. A secondary function would be to provide additional propulsion using the ascent or descent stage propulsion.

The LEM-Lab, basically a stripped ascent stage with the minimum hardware required to use CSM ECS and EPS would provide approximately 240 cu. ft. and weigh 1250 lbs. The current Apollo LEM could serve by simply offloading propellants and expendables. The respective figures would be 180 cu. ft. and 4000 lbs.

The unresolved areas are largely in how the LEM-Lab can be used rather than specific problems in the modification.

Earth-Orbit LEM - A modified LEM for use with the CSM as an independent, separable spacecraft in extended earth orbital missions.

Because of independent operation this derivative must retain most of the LEM functions. The potential of supplementing the CSM subsystems for extended missions merits study.

LEM-Shelter - A modified LEM delivered unmanned from lunar orbit to the lunar surface to provide shelter for an extended surface mission of the LEM-Taxi crew.

LEM subsystems not required, including ascent propulsion, would be removed to provide increases in volume and weight for the Shelter mission payload and additional expendables. Significant changes from the current LEM would be expected in cryogenic storage, obstacle avoidance for unmanned landing, radiation shielding, and electrical power generation.

Duration, mode, and location during storage require further study. For surface storage the current hydrogen tanks and open-cycle EPS limit the pre-utilization storage period to approximately 12 days, for a hydrogen weight penalty of 1000 lbs. If a closed-cycle EPS were used the respective figures would be 45 days and 800 lbs. It appears that tank redesign and closed-cycle EPS would be required for storage periods of 3 to 6 months.

Radiation shielding for the crew is a problem. If additional shielding were not provided there is about a 25% chance of an abort being required due to radiation during a 14-day surface staytime. Means of reducing this probability should be investigated.

LEM-Taxi - A modified LEM for delivery of two men near the LEM-Shelter on the lunar surface, quiescent storage during the extended surface mission, and return of the crew to the CSM in lunar orbit.

The Taxi would perform the nominal Apollo mission with the addition of an extended waiting period on the surface. It is estimated the separation weight of the Taxi would be 100 to 1000 lbs. greater than that of the LEM, which does not include any scientific payload to be returned following a 14-day mission. Closed-cycle ECS and EPS would reduce this penalty.

Questionable areas for future study include abort capability and the extent of activity during the storage period, which is influenced by the need for active thermal control and system status monitoring.

The four derivatives considered appear to be both suitable and obtainable for the AES missions. In some cases the extension of capability, increasing surface time to 14 days with long-term storage for example, can be obtained only by major subsystem changes. In all cases the LEM derivatives represent compromises and are suitable only if viewed as interim improvements of the existing Apollo LEM. Further, the solution of basic problems, as in the previous example of the LEM-Shelter, may involve effort comparable to the development of more suitable modules and derivatives having greater potential. The relative merits of such compromises with the attendant limitations on crew size, volume and payload weight, mobility, and other constraining factors should be considered, as opposed to other similar approaches under AES-type ground rules.

ACKNOWLEDGMENTS

The many contributions of others are gratefully acknowledged: in particular, those of T.L. Powers, for many helpful discussions and suggestions; and R.F. Hergert, MSC-ASTD contract monitor, and H. Wagner, GAEC Project Engineer, for making available preliminary data obtained during the current LEM Utilization Study contract.

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APPENDIX

LEM DERIVATIVE: SUBSYSTEM MODIFICATIONS AND WEIGHT ESTIMATES

The requirements to be met by the AES LEM derivative vary considerably and result, in some cases, in extensive modification of the Apollo LEM subsystems. In this section the four basic derivatives and their respective subsystem modifications are briefly described.

In some cases a subsystem or parts of a subsystem are deleted. No distinction has been made as to when deletion, substitution, or modification are done; that is, whether the hardware is removed from a completed or partially completed LEM or simply not installed from the beginning or as to the relative difficulty involved.

Weights are estimated and major problem areas, significant changes, and unresolved or questionable areas are noted. Weight figures are partially based on information from the GAEC mass property report reflecting LEM status of January 1, 1965, and from current preliminary data obtained by GAEC in the LEM Utilization Study, as of January 13, 1965. These weight figures show net weight change and do not indicate the extent of hardware change or substitution.

It should be noted that although part of the information has been obtained from GAEC and has been useful in this study, it is of a preliminary nature; and this report does not and is not intended to present or appraise the GAEC position on LEM derivatives.

1.0 LEM-LAB

1.1 Description

A modified LEM ascent stage attached to the CSM for use as a laboratory in earth and lunar orbital missions. The descent stage is used if additional propulsion is required. LEM-Lab, essentially a stripped ascent stage, would have a pressurized volume of approximately 240 cu. ft. (Apollo LEM, 180 cu. ft.) and weight of approximately 1200 lb.

1.2 Subsystems

Crew provisions: removed, except restraint harness. Crew is entirely dependent on CSM for life support.

Controls and displays: removed. Add basic instrument panel and console.

EPS: removed. Add minimal wiring for experiments and lighting.

ECS: removed. Add fan, ducting, and plumbing for use of CSM ECS.

G&N, S&C: removed

Propulsion: removed from ascent stage. Descent stage propulsion unchanged, if used.

Structure: increase meteoroid shielding. Possibly add external airlock. Use existing hardpoints for mounting internal and external scientific equipment.

Communications and Instrumentation: removed. Provide CSM intercom with provision for communicating with extravehicular crew.

1.3 Basic LEM-Lab (Ascent Stage) Weight

Basic ascent stage structure	1101
Remove: equipment supports & covers	- 307
Add: Crew restraints Minimum lighting, wiring, displays, fan and ducting, communications, meteoroid shielding, airlock	+ 455
TOTAL	1250 lb.

1.4 Questions, Changes, and Problem Areas

Unresolved: Integration of experiments
Need for airlock
Storage of data (film, tapes)
Meteoroid and radiation protection required
Extent of dependence on CSM

Significant changes: Removal of all Apollo LEM subsystems.

2.0 EARTH-ORBIT LEM

2.1 Description

Modified LEM ascent and descent stages for use with CSM as an independent, separable spacecraft in extended earth orbital missions.

2.2 Subsystems

Crew Provisions: Probable decrease in requirements because of part-time dependence on CSM. Depends on length of time separated from CSM. Present expendables good for 4 man days only.

Controls and displays: Add basic panel and console for experiments.

EPS: Extend fuel cell life and/or increase battery supplement. Requirements dependent on mission and power profile.

ECS: No change required for crew. Power profile and mission operations selected have significant effect on water required for thermal control. For extended missions separated from CSM, probably would need closed cycle ECS.

G&N, S&C: No change. Possibly offload RCS propellant.

Propulsion: Remove ascent propulsion. Possibly offload descent propellant.

Structure: No change, except possible airlock. Meteoroid and radiation shielding for extended separation.

Communications and Instrumentation: No change. May need more extensive CEM LEM links.

2.3 Earth-Orbit LEM Weight

Remove ascent propulsion	5244
Add airlock	100
Net change, available for payload ..... approx.	5000 lb.

2.4 Questions, Changes, and Problem Areas

Unresolved: Need for airlock
Extent of part-time dependence on CSM
Meteoroid and radiation protection required
Use of ascent and/or descent propulsion

Significant changes: Remove ascent propulsion
ECS and EPS modifications (possible)

Major problems: Fuel cell life time
Definition of mission.

3.0 LEM-SHELTER

3.1 Description

Modified LEM delivered unmanned to provide shelter for 14 day surface mission of the LEM Taxi crew.

3.2 Subsystems

Crew Provisions: Significant increase over Apollo requirements because of expendables for extended duration and increased extra-vehicular activities. Provide spare suits and backpacks.

Control and Displays: Manned flight controls not required but must have those controls and displays needed for lunar orbit checkout prior to separation and for surface mission. Add displays for monitoring status of LEM Taxi.

G&N, S&C: Add unmanned landing capability (obstacle avoidance). Offload RCS. Abort contingencies, ascent capability not needed.

EPS: Fuel cells require capability for either shutdown/storage/restart, continuous idling (excessive cryogenic expendables penalty), or storage/start. There are several possible approaches, all requiring extensive modification and, most likely, a closed EPS cycle. Storage of expendables requires development.

ECS: Significant increase in expendables because of relatively long-term storage and active phases.

Propulsion: Remove ascent propulsion. Possibly offload descent propellant.

Structures: Increase meteoroid shielding. Radiation shielding penalty may be excessive. Add external airlocks and, if closed cycle, ECS/EPS radiator(s).

Communications and Instrumentation: Modify to meet requirements for transmitting status during storage phase and for monitoring LEM Taxi status during active phase. Unmanned landing may increase requirements, depending on mode selected.

3.3 LEM-Shelter Weight

If the Shelter is to have storage periods of 3 months to 6 months, based on launch rates, then storage of expendables will have to be improved well beyond current LEM capability. Further, if the LEM Shelter/Taxi paired missions are to have reasonable operational flexibility, then the current ECS and EPS open cycles may not be suitable.

Assumptions made for the Shelter subsystems to estimate a weight figure are:

(1) Closed ECS and EPS cycles, similar to CSM

(2) Hydrogen storage in excess of 3 months is attainable for 800 lbs.

Remove:	G&N, S&C	- 114
	Experiment payload	- 170
	Propulsion	- 5244
	RCS	- 570
	Controls & displays	- 105
	ECS, EPS, other	- 800
Add:	ECS and EPS	+ 2130
	Structure (inc. radiators)	+ 700
	Crew provisions	+ 150
	Pre-usage storage	+ 800
Net change, available for payload*		3223 lbs.

* Payload should include spare suits and backpacks - approx. 280 lbs.

3.4 Questions, Changes, and Problem Areas

Unresolved:

Pre-utilization storage time, mode, and location
Status monitoring
Unmanned, automatic landing mode
Need for airlock, pump down
Radiation hazard protection
Adequacy of landing gear - depends on unmanned landing

Significant changes:

Closed ECS and EPS cycles
Cryogenic tanks

Major problems:

Cryogenic storage
Fuel cell life
General uprating of component life
Radiation protection

4.0 LEM-TAXI

4.1 Description

Modified LEM for delivery of two men near LEM-Shelter on lunar surface, quiescent storage for 14 days, and return of crew to CSM.

4.2 Subsystems

Crew Provisions: No change.

Control and Displays: No change.

G&N, S&C: No change. IMU thermal problem.

EPS: Excessive penalty with present system unless fuel cells can be shut down during quiescent state. Present cryogenics may not be suitable.

ECS: Increased water requirements for day landing.

Propulsion: No change. Additional insulation required to limit propellant temperatures.

Structures: Increase meteoroid protection.

Communications and Instrumentation: Taxi and Shelter share LEM frequencies and one may have to be modified. (Question of impact on CM and earth-based communications). Current LEM instrumentation and telemetry suitable for status monitoring during storage phase.

4.3 LEM-Taxi Weight

Case 1. Assume: normal LEM systems
one fuel cell idling during quiescent storage
insulating present ascent hydrogen is sufficient

Remove:	scientific equipment	-250
	TV	- 11
Add:	micrometeoroid shielding	35
	ECS water and tanks	205
	EPS, fill existing tanks	27
	insulation	35
Net change,	increase	41 lb.
	(sep. wt. increase	106 lb.)

Case 2. Assume: normal LEM systems
three fuel cells idling during quiescent storage
insulating present ascent hydrogen is sufficient

Remove:	scientific equipment	-250
	TV	- 11
Add:	micrometeoroid shielding	35
	ECS water and tanks	509
	EPS, add reactants and tanks	103
	insulation	35
	increase	416 lb.
	(sep. wt. increase	917 lb.)

4.4 Questions, Changes, and Problem Areas

Unresolved:

IMU temperature limits
Abort capability/latitude constraint
Landing ejecta damage to Shelter
Status monitoring
Activity or extent of quiescence during storage

Significant Changes: None

Major Problems:

Excessive weight
Fuel cell life

5.0 TYPICAL WEIGHT ESTIMATE

The following table shows the current subsystem weights and the type of weight changes expected in a LEM modification. In this particular case the modification is for a LEM-Shelter assumed to have no pre-utilization storage, current open-cycle EPS and ECS, 1 kw average power, and 63 repressurization cycles (nominal Apollo rate).

Shelter Ascent Stage	1/1/65 Sep.Wt.	Removed	Added	Remarks
1.0 Structure	1101.3	68.8		remove supports and panels
			200	add meteoroid shielding (100) & equipment supports
2.0 S&C	70.6	36.0		remove abort capability
3.0 G&N	276.9	36.9		remove abort capability
4.0 Crew Provisions	132.3	111.8		remove all except lighting
			325	add furnishings, food, LiOH
(crew, backpacks, suits)	576.7			
5.0 ECS	316.2	74.9		remove ascent water & tank, LiOH
			2309	add water & tanks
			159	add LiOH
			705	add oxygen & tanks
7.0 Instrumentation Operational	190.5			
Scientific	80.0	80.0		remove

(continued)

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Shelter Ascent Stage	1/1/65 Sep.Wt.	Removed	Added	Remarks
8.0 EPS	941.1	191.8		remove one fuel cell (66) & ascent reactants & tanks
			669	add hydrogen & tanks
			334	add oxygen & tanks
9.0 Propulsion				
Dry	589.4	589.4		remove
Propellant	4655.2	4655.2		remove
10.0 RCS				
Dry	314.5	170.0		remove redundancy
Propellant	519.0	400.0		remove ΔV & part of reaction control propellant
11.0 Communications	115.5			
12.0 C&D	223.3	105.4		remove C&D from S&C, instrumentation, propulsion, & RCS
Total ascent stage at separation	10102.5	-6520	+4701	

[redacted]

Shelter Descent Stage	1/1/65 Sep.Wt.	Removed	Added	Remarks
1.0 Structure	1208.3	15.0		remove supports
2.0 S&C	13.7	13.7		remove
3.0 G&N	28.0	28.0		remove
4.0 Crew Provisions	25.5	25.5		remove
5.0 ECS	168.7	7.2		remove LiOH
		135.9		offload lunar stay water
6.0 Landing Gear	410.0			unchanged
7.0 Instrumentation				
Operational	5.0			
Scientific	170.0	170.0		remove
8.0 EPS	322.1	138.2		offload lunar stay reactants
9.0 Propulsion				
Dry	1553.5			
Propellant	16424.7			
10.0 RCS				
Dry	-			
Propellant	-			
11.0 Communications	14.1	11.5		remove TV
12.0 C&D	-			
Total descent stage at separation	20343.6	-547.0	0*	
NET REMOVED		-7,067		
NET ADDED			+4,701	
AVAILABLE FOR PAYLOAD			+2,366	
TOTAL SEPARATION WEIGHT	30446 lb.			

* Added items shown in ascent stage column may be in ascent or descent stages.

[redacted]